Is energy performance too taxing? A CAMA approach to modelling residential energy in housing in Northern Ireland

Emerald Journal of European Real Estate Research

Is Energy Performance too taxing: A CAMA approach to modelling residential energy in housing in Northern Ireland

Journal:	*Journal of European Real Estate Research*
Manuscript ID	JERER-06-2016-0023.R3
Manuscript Type:	Research Paper
Keywords:	energy efficiency, energy performance, mass appraisal, property taxation, housing policy, CAMA

Article Title Page

[Article title: Is Energy Performance too taxing: A CAMA approach to modelling residential energy in housing in Northern Ireland]

[Author Details]

Author 1 Name: Dr Peadar Davis
Department: School of the Built Environment
University: Ulster University
Town/City: Newtownabbey
State (US only):
Country: Northern Ireland

Author 2 Name: Dr Michael McCord
Department: School of the Built Environment
University: Ulster University
Town/City: Newtownabbey
State (US only):
Country: Northern Ireland

Author 3 Name: Prof William McCluskey
Department: African Tax Institute
University: University of Pretoria
Town/City: Pretoria
State (US only):
Country: South Africa

Author 4 Name: Dr Erin Montgomery
Department: School of the Built Environment
University: Ulster University
Town/City: Newtownabbey
State (US only):
Country: Northern Ireland

Author 5 Name: Prof Martin Haran
Department: School of the Built Environment
University: Ulster University
Town/City: Newtownabbey
State (US only):
Country: Northern Ireland

Author 6 Name: Dr John McCord
Department: School of Law
University: Ulster University
Town/City: Newtownabbey
State (US only):
Country: Northern Ireland

Corresponding author: Room 04B08a, Ulster University, School of the Built Environment, Shore Road, Newtownabbey, Co. Antrim, BT37 0QB, N. Ireland. Tel: +442890366507
[Corresponding Author's Email:] **pt.davis@ulster.ac.uk**

☐ *Please check this box if you do not wish your email address to be published*

NOTE: affiliations should appear as the following: Department (if applicable); Institution; City; State (US only); Country.
No further information or detail should be included

Acknowledgments (if applicable): Land and Property Services, Department of Finance, Northern Ireland for data provision

Structured Abstract [Mandatory] – Please structure in sections as shown in the author guidelines

Purpose: Buildings contribute significantly to CO_2 production. They are also subject to considerable taxation based on value. Analysis shows that whilst similar attributes contribute to both value and CO_2 production, there is generally a loose relationship between the two. If we wish to use taxation to affect policy change (drive energy efficiency behaviour), we are unlikely to achieve this using only the current tax base (value), or by increasing the tax take off this current tax base (unlike extra taxation of cigarettes to discourage smoking, for example). Taxation of buildings on the basis of energy efficiency is hampered by the lack of current evidence of performance. This research models the now obligatory (at sale or letting) Energy Performance Certificate (EPC) data to derive an acceptable appraisal model (marked to market, being the EPC scores) and deploys this to the entire population of properties. This provides an alternative tax base with which to model the effects of a tax base switch to energy efficiency and to understand the tax incidence effects of such a policy.
Design: The research employs a multiplicative hedonic approach to model energy efficiency utilising EPC holding properties in a UK jurisdiction (Northern Ireland (NI)) as the sample. This model is used to estimate discrete energy assessments for each property in the wider population, utilising attributes held in the domestic rating (property tax) database for NI (700,000+ properties). This produces a robust estimate of the EPC for every property in its current condition and its cost effective improved condition. This energy assessment based tax base is further utilised to estimate a new millage rate and property tax bill (green property tax) which is compared against the existing property tax based on value to allow tax incidence changes to be analysed.
Findings: The findings show that such a policy would significantly redistribute the tax burden and would have a variety of expected and some unexpected effects. The results indicate that whilst assessing the energy performance of houses can be a complex process involving many parameters, much of the explanatory power can be achieved via a relatively small number of input variables, often already held by property tax jurisdictions. This offers the opportunity for useful housing stock modelling – such as the savings possible from power switching. The research also identifies that whilst urban areas display the expected 'heat island' effect in terms of energy consumption, urban properties are on average more efficient than suburban / rural properties. This facilitates spatial targeting of policy messages and initiatives.
Research limitations/implications: Analogous with other studies, data deficiencies introduce the risk of omitted variable bias. Modelling of the energy efficiency in the sample is limited to property attributes that are available for the wider population of properties. Whilst this limits the modelling exercise, it is a perennial issue facing mass appraisal worldwide (where knowledge of the transacted sample attributes generally exceeds knowledge of the unsold properties). That said, the research demonstrates the benefits of sharing data and improving knowledge of the housing stock, as taxation databases would be stronger, augmented with EPC derived property attributes for example.
Originality/value: The EPC lead in time for wide residential coverage is likely to be considerable. The paper contributes to emerging literature and policy debate surrounding the effect, performance measurement and implementation of energy efficiency certification, through a greater understanding of the sectorial and geographical dispersion of energy efficiency. It provides high level research to help guide policy and decision-making, identifying key locales where there is more of a physical problem and locations where there is more to gain in terms of targeting energy improvement and / or encouraging behavioural change. The paper also allows a glimpse of the implications of a change towards a taxation regime based on energy efficiency, which contributes to the debate surrounding the 'greening' of property based taxes.

Keywords [Mandatory]: Energy efficiency, Energy performance, Mass Appraisal, Property Taxation, Housing Policy

JEL Classification:

Article Classification [Mandatory]: Research Paper

For internal production use only

Running Heads:

Is Energy Performance too taxing: A CAMA approach to modelling residential energy in housing in Northern Ireland

ABSRACT.

Purpose: Buildings contribute significantly to CO_2 production. They are also subject to considerable taxation based on value. Analysis shows that whilst similar attributes contribute to both value and CO_2 production, there is generally a loose relationship between the two. If we wish to use taxation to affect policy change (drive energy efficiency behaviour), we are unlikely to achieve this using only the current tax base (value), or by increasing the tax take off this current tax base (unlike extra taxation of cigarettes to discourage smoking, for example). Taxation of buildings on the basis of energy efficiency is hampered by the lack of current evidence of performance. This research models the now obligatory (at sale or letting) Energy Performance Certificate (EPC) data to derive an acceptable appraisal model (marked to market, being the EPC scores) and deploys this to the entire population of properties. This provides an alternative tax base with which to model the effects of a tax base switch to energy efficiency and to understand the tax incidence effects of such a policy.

Design: The research employs a multiplicative hedonic approach to model energy efficiency utilising EPC holding properties in a UK jurisdiction (Northern Ireland (NI)) as the sample. This model is used to estimate discrete energy assessments for each property in the wider population, utilising attributes held in the domestic rating (property tax) database for NI (700,000+ properties). This produces a robust estimate of the EPC for every property in its current condition and its cost effective improved condition. This energy assessment based tax base is further utilised to estimate a new millage rate and property tax bill (green property tax) which is compared against the existing property tax based on value to allow tax incidence changes to be analysed.

Findings: The findings show that such a policy would significantly redistribute the tax burden and would have a variety of expected and some unexpected effects. The results indicate that whilst assessing the energy performance of houses can be a complex process involving many parameters, much of the explanatory power can be achieved via a relatively small number of input variables, often already held by property tax jurisdictions. This offers the opportunity for useful housing stock modelling – such as the savings possible from power switching. The research also identifies that whilst urban areas display the expected 'heat island' effect in terms of energy consumption, urban properties are on average more efficient than suburban / rural properties. This facilitates spatial targeting of policy messages and initiatives.

Research limitations/implications: Analogous with other studies, data deficiencies introduce the risk of omitted variable bias. Modelling of the energy efficiency in the sample is limited to property attributes that are available for the wider population of properties. Whilst this limits the modelling exercise, it is a perennial issue facing mass appraisal worldwide (where knowledge of the transacted sample attributes generally exceeds knowledge of the unsold properties). That said, the research demonstrates the benefits of sharing data and improving knowledge of the housing stock, as taxation databases would be stronger, augmented with EPC derived property attributes for example.

Originality/value: The EPC lead in time for wide residential coverage is likely to be considerable. The paper contributes to emerging literature and policy debate surrounding the effect, performance measurement and implementation of energy efficiency certification, through a greater understanding of the sectorial and geographical dispersion of energy efficiency. It provides high level research to help guide policy and decision-making, identifying key locales where there is more of a physical problem and locations where there

is more to gain in terms of targeting energy improvement and / or encouraging behavioural change. The paper also allows a glimpse of the implications of a change towards a taxation regime based on energy efficiency, which contributes to the debate surrounding the 'greening' of property based taxes.

Keywords Energy efficiency, Energy performance, Mass Appraisal, Property Taxation, Housing Policy

Paper type Research paper

1.0 Introduction

Following the Kyoto Protocol, the reduction of energy consumption attributable to buildings has become a key Government policy objective. In Europe, the Energy Performance in Buildings Directive has moved mandatory energy performance disclosure to the forefront of the energy and climate change policy agenda (Berry *et al*., 2008), requiring all buildings at construction, sale or rent to have certificates providing information about their energy performance, through a rating based ultimately on an assessment of CO_2 emissions. The Energy Performance Certificates (EPCs) which are the result of this policy are intended to inform potential buyers or occupiers about the intrinsic energy performance of a building (Fuerst *et al*., 2011). The principle underlying the Directive is to provide accurate and standardised information relating to inherent building energy efficiency to the market place, in order to change consumer behaviour and permit prospective owners, occupiers and tenants to recognize and integrate energy efficiency characteristics in determining value (Davis *et al*., 2015).

In recent years there has been increased speculation regarding the link that exists between market value and environmental performance. Although practitioners and academics generally perceive there to be a positive relationship between value and energy efficiency (alongside other sustainable practices), there is a lack of robust and balanced evidence that quantifies the financial gain that can be achieved from high environmental performance within the residential sector (Waters and Elder, 2007). Some valuation studies suggest that property prices are driven by demand and, as yet, there is little evidence to indicate increased demand for sustainable or efficient buildings (RICS, 2010; Sayce *et al*., 2010). Indeed, how energy efficiency is valued in the residential property market in terms of resale or appraisal value is of growing concern (McNamara, 2008; Sayce *et al.*, 2010) and the relationship between energy performance and property value remains nebulous, complex and under-researched (Davis *et al*., 2015). Increasing awareness and focus on energy efficiency has the potential to introduce market uncertainty in both the residential sales and rental sectors, given the imperfect nature of the residential housing market, relating to externalities and asymmetric information (Davis *et al*., 2015). This is further compounded by the embryonic nature of studies investigating energy performance geographically and the paucity of available data (Fuerst *et al*., 2011). Moreover, literature exploring consumer attitudes to EPCs imply that they currently have low credibility with some property professionals (Home Sale Network, 2010; RICS, 2010) and limited impact on householder choices.

With the emergence of the green agenda in the UK, much policy effort has emphasized the need for improving the energy efficiency of housing. In particular, government policy documents have focused on new forms of incentivisation mechanisms intended to increase the 'value' of renewable and energy efficiency installations for householders; such as the Feed in Tariffs and Pay as You Save schemes (HM Government, 2009; The Coalition, 2010). Many jurisdictions have also made efforts to foster knowledge and improve the energy efficiency of housing stock, to better target funding and awareness campaigns aimed at encouraging upgrades. In this regard, particular jurisdictions are now seeking to reward / encourage such activity via *tax* incentivisation. Despite this policy focus, there remains limited insights as to the energy performance of existing (unsold) housing, and strategic insights as to where policy agendas should focus, at what scale and via what medium. As highlighted by Fawcett and Boardman (2009), reducing energy use and carbon emissions within the *existing* housing stock requires a substantial and rapid transformation of the entire sector. This is a major challenge for UK and EU level policy. Indeed, Davis *et al*. (2015) illustrate this point, underlining that energy policy cannot change the laws of economics and only so much can be achieved with a housing stock which has displayed admirable longevity – itself a rather underestimated contributor to the totality of energy efficiency of housing. Pertinently, Fawcett and Boardman (2009) suggest that the frequency with which people move around in the housing stock affects the rate at which the housing stock is covered by EPCs. Based on household move rates in England for 2005/6 (market peak) calculations, they estimate that EPCs issued (over a year period) equated to just over 10% of housing stock - implying marginal uptake of EPC relative to the total population housing stock - the result of which is that the present process will not result in a comprehensive labelling system for many years.

Arguably, energy policy cannot wait for this process to mature. This would suggest that more robust methods for effective asset management of the domestic housing stock are needed to help guide policy and decision making. To achieve this enhanced understanding, novel approaches are required which move beyond modelling existing sale transactions to capture the EPC and housing relationship. In this regard, Computer Assisted Mass Appraisal (CAMA) techniques can be employed to assist housing stock population energy assessment. Utilising hedonic and spatial analysis is well established in the field of property valuation for taxation purposes. In this taxation assessment role, statistical approaches are deployed on large datasets of property attribute data. Sale price in a sample of sold properties is used to estimate value in the general population. Utilising this approach, this research develops and blends several large databases of property data to establish a basis for statistical modelling of energy performance. This culminates in the provision of a methodology which may be broadly deployed in other regions to gain a deeper understanding of energy efficiency in the housing stock and to provide a data test-bed to model the performance potential of a range of potential policy options, including the use of such assessments as an alternative (or additional) tax base for annual property taxation.

Pressure to introduce fiscal and other measures to achieve behaviour change in the built environment has, to date, focused on schemes pertaining to building services upgrades (eg boiler replacement grants and fuel switching incentives) and retrofitting of features such as insulation and glazing with modern alternatives. Moving forward, current UK legislation will act to make the most inefficient properties effectively unlettable and unsaleable. A more direct taxation of property based on its overall energy efficiency, as an alternative to, or in addition to value based taxation, has been mooted but is as yet untried. In considering such an alternative, it is important to understand the extent to which energy efficiency is currently capitalized into property values – that is, does existing property taxation effectively tax energy inefficiency - and also to consider the redistributive effects on taxation incidence which would occur, in terms of geographical dispersion, fairness and equity.

The paper is structured as follows; Section 2 discusses the current literature pertaining to EPC performance and property markets, to provide a better understanding of the link and the potential requirement for an alternative tax base fiscal perspective. Section 3 presents the data and methodological framework utilised, with Section 4 presenting the results and discussion of the key findings. Conclusions are proffered in Section 6.

2.0 Energy Performance and Property Value

Over the past thirty years studies examining the housing market have explored of the nature of the relationship between energy performance and property value in the residential sector (Laquatra, 1986; Dinan et al., 1989; Halvorsen and Pollakowski, 1981; Johnson and Kaserman, 1983; Quigley and Rubinfeld, 1989). These seminal studies generally illustrated that there is an effect between energy efficiency and pricing. Given the heightened agenda over the past decade towards energy performance in buildings, coupled with more readily available data, there has been a renewed interest in measuring the effects of energy performance in housing markets. In recent years, a number of studies have utilised explicit measures of energy performance on property value. One of the first studies to investigate the price effect of mandatory energy labelling in a residential real estate market was carried out by the Australian Bureau of Statistics (2008). Berry *et al*. (2008) examined the relationship between energy performance and detached house prices between 2006 and 2008, finding that House Energy Ratings (HER) had a positive relationship with price, noting a premium for every increase in energy efficient rating[1]. Pertinently they found evidence of a non-linear effect, with the marginal pricing effect declining as rating increases. A study conducted by Brounen and Kok (2011) performed the first empirical investigation of large scale labelling, examining the relationship between EPC ratings and achieved residential sale prices in the Netherlands. The findings indicated that property markets do capitalize on the value of energy efficiency investments, estimating a price premium of up to 15 percent for energy-efficient homes. Significantly, the research also suggests that sellers use EPCs to resolve the asymmetric information problem in high competition areas, rather than to signal superior quality.

A recent paper by Högberg (2013) examined the impact of energy performance on single-family home selling prices in Sweden. Employing a hedonic framework, the findings illustrated that enhanced energy performance affects selling prices positively, with the results showing that a marginal effect of a 1 percent decrease in standard energy consumption results in an increase in selling price by an average of 0.044 percent. The results suggest that home buyers do take into account the information available in the EPCs and put a price premium on energy efficiency. However, Högberg (2013) does indicate that energy efficiency recommendations require a discount on the selling price, implying that sellers should have strong incentives to improve energy efficiency prior to selling in order to reap the price premium rather than lose the value of the discount. Similarly, Cerin *et al*. (2014) in a study investigating the Swedish housing market examine whether a price premium exists for mandatory EPCs post EU directive implementation. The analysis, based on 2009/2010 sales transactions (67,599), finds energy performance to be associated with price premiums within particular segments of the housing stock. The results suggest that EPCs, whilst presenting some mixed results, do have a role to play in determining market value.

[1] For full discussion see Berry, S., Marker, T. and Chevalier, T. (2008), “Modelling the relationship between energy efficiency attributes and house price: the case of detached houses sold in the Australian capital territory in 2005 and 2006”, 2008 ACEEE Summer Study on Energy Efficiency in Buildings, pp. 2.52-2.56, available at: www.aceee.org/sites/default/files/publications/ proceedings/SS08_Panel2_Paper05.pdf.

These findings are also concurrent with Fuerst *et al*. (2015) who examine whether energy efficiency matters to home-buyers in England. Their study investigates whether energy performance ratings, as measured by mandatory Energy Performance Certificates (EPCs), are reflected in the sale prices of residential properties, using a substantial dataset of 333,095 dwellings sold between 1995 and 2012. Applying a standard hedonic methodology and an augmented repeat sales regression, the findings showed positive relationships between the energy efficiency rating of a dwelling and the transaction price per square metre, as much as 5% (£8,900) for those in categories A and B. Pertinently, the authors suggest that the price effects of superior energy performance tend to be higher for terraced dwellings and apartments compared to detached and semi-detached dwellings. Nonetheless, they do illustrate that the evidence is less clear-cut for rates of house price growth but remains supportive of a positive association. Overall, the results of this study suggest that energy efficiency labels have a measurable and significant impact on house prices in England, however caveat this indicating that there is considerable variation in these effects by region and property types. In a similar fashion, Davis *et al*. (2015) investigated the relationship between energy performance and property sale price in the Belfast housing market. Employing a hedonic pricing specification, their study measures the effect of energy performance certificates (EPCs) on residential property value (3,797 residential sales transactions). Their results indicate a small but positive relationship between energy performance and selling prices. Nonetheless, the findings point towards strong preference, demand tastes and a complex (inter) intra-relationship between EPCs and their capitalisation into property value. Pertinently, the findings point towards any energy-efficient-related price effect to be marginal alongside more "quality" based market signalling. In an additional Irish context, Hyland *et al*. (2013) applied a standard hedonic technique to investigate the impact of energy efficiency ratings on capital and rental asking prices for 15,060 dwellings in Ireland between 2008 and 2012. Employing the Heckman procedure to control for selection bias, their results showed a 9.3% price premium for A-rated compared to D-rated dwellings, 5.5% for a B-rating, and a 10.6% discount for F and G ratings. For rented dwellings the premium for an A-rating was 1.8%, 3.9% for a B rating, a discount of 1.9% for E ratings and 3.2% for F and G ratings. Furthermore, a recent EU study has identified a positive premium across a number of EU countries. Notably, the findings reveal that there are again clear indications from the property market that energy efficiency is capitalized, with the effect of a one-letter improvement in energy efficiency yielding a 2.8% price premium in the sales market and 1.4% in the lettings market.

In conjunction with this over the past decade there has been increased research activity examining buyer sentiment towards energy performance, with the literature diverging from technological performance issues towards exploration of perceptions of the value of sustainable or 'green' features (Sayce et al., 2010). A key strand of the literature has pointed towards consumer based analysis and the willingness to pay for energy efficient housing. The hypothesis of rational market valuations for home energy efficiency has gained empirical support, both in terms of what home buyers are willing to pay and how appraisers value energy-efficiency investments (Nevin *et al.*, 1999; Popescu *et al.*, 2009). An emerging corpus of evidence suggests that buildings with superior environmental performance deliver a bundle of benefits to occupiers and investors, including a greater level of services, subsidies, monetary return and tax benefits (Ürge-Vorsatz *et al.*, 2009; Eichholtz *et al.*, 2010). According to Sayce et al. (2010) studies show a willingness to pay a premium for energy performance with results indicating that attributes associated with a more energy-efficient home - such as better insulation or central heating (Bronen and Kok, 2011; Banfi *et al.*, 2008;

Wilhelmsson, 2004) or fuel type such as gas heating (Laquatra *et al*., 2002; Wilhelmsson, 2004) contributing to a higher transaction price.

With regards to consumer sentiment, Eves and Kippes (2010) examined the buyer awareness and acceptance of environmental and energy efficiency measures within the context of the New Zealand residential property market. Employing an extensive survey, the results show that regardless of income levels, buyers still consider that the most important factor in the house purchase decision is the location of the property and its selling price. The authors suggest that although the awareness of green housing issues and energy efficiency is growing in the residential property market, it is only a major consideration for young and older buyers in the high income brackets and is only of minor importance for all other buyer sectors. Indeed, they highlight that many of the voluntary measures introduced by Governments to improve the energy efficiency of housing are not considered important by buyers, indicating that a more mandatory approach may have to be undertaken to improve energy efficiency in established housing markets. Research by Nair *et al*. (2010) used survey data based on 3,000 owners of detached houses to analyse the factors that influence the adoption of investment measures to improve the energy efficiency of their buildings. Their findings illustrated that whilst energy efficiency is considered important by homeowners, a majority adopted non-investment based measures, supporting earlier findings (Kempton, 1985; Forstater *et al*., 2007). Significantly, the findings revealed that behaviour was demarcated by income. The authors conclude by highlighting that effective communication to increase awareness of energy efficient building envelope measures especially its cost-effectiveness, may improve the adoption rate of such measures. They suggest that information stressing the *loss* incurred by homeowners who do *not* adopt energy efficiency measures may be more effective than focusing on the economic gains (the classic loss aversion concept (Tversky & Kahneman, 1991)). This indicates a requirement for increased flow of information and government policy measures (including fiscal measures) to facilitate the adoption of energy efficiency measures.

In another vein, Fregonara *et al*. (2014) scrutinised agents' perception of EPCs contribution to list prices for attracting buyers and influencing house values. Using data for the Turin housing market, the authors use a traditional hedonic approach to assess the EPC level contribution on listing price. Comparing two models, the authors ascertain that the EPC level effects on listing prices are isolated: only level "F" is significant. They conclude that the weak relationship between listing price and energy efficiency is evidence that energy performance is not yet taken into account by real estate agents. This helps to explain the low attention given to EPC assessments by potential buyers. This exacerbates lack of awareness of the cost-benefit relationship between EPC level and housing costs and assumptions that such matters are already capitalized into value.

In summary, whilst there are fairly plausible *a priori* grounds to expect a willingness to pay for energy efficiency by potential or existing residential owners, the empirical research on the effect of energy or environmental labelling remains unclear. It would appear that capitalisation effects, whilst generally positive, are small and inconsistent across the performance range. Given this state of affairs, there appears to be merit in investigating the effects of a more direct fiscal (dis)incentive to inform consumer choice and influence behaviour via the taxation system. With such a weak link between EPC and value, taxation based on value does not appear to be an effective policy option to achieve environmental objectives. Creation of an alternative tax base, which more directly reflects energy efficiency may allow such policy instruments to be modelled and outcomes to be investigated.

Property taxation has not traditionally been used to encourage behaviour change, with such effects generally being unintended consequences of tax burden mitigation (e.g. the narrow buildings resulting from the Dutch 'frontage tax' and the constructive vandalism to render vacant buildings untaxable under UK Vacant Rating). The rationale of the ad valorem tax base has been to establish a uniform, fair and equitable sharing mechanism (McCluskey *et al.*, 2013, Hodge *et al.*, 2016). That said, taxation can be a very effective mechanism for behaviour modification and also as a revenue source to pay for the disamenity effect of the underlying undesirable activity (in this case use of energy inefficient buildings). As such, there is considerable public tax policy precedent to support the introduction of a recurrent taxation on property to encourage its efficient usage and to fund mitigation and amelioration activity – such as tax breaks and grants for energy efficiency initiatives, for example.

3.0 Methodological Framework

Data and model development

Modelling of energy performance was carried out on an original data set of 144,613 properties which had been marketed for sale or to let or had otherwise required the production of an EPC in the Northern Ireland jurisdiction (forming the sample data). The EPC assessments are derived from a comprehensive EPC database which encompasses 54 metrics included in EPC assessments[2] such as property type, age, size, location, construction method and operational aspects such as type of lighting. The EPC database is a publicly owned register and was accessed via Landmark (a commercial organisation which hosts the data on behalf of the statutory authority and who can provide a cost effective method of data gathering for a fee, rather than the cost and time prohibitive alternative of searching for EPC holding properties on a case by case basis). This database, as with other EPC data from the UK and elsewhere in Europe, does not contain any price information whatsoever. An additional database was utilised, drawn from the NI Domestic Property Taxation register/database[3] which contains *circa* 730,000 properties, comprising 95%+ coverage of the NI housing stock (forming the population data). The taxation database contains a number of property attributes, some of which were able to be manipulated to provide a consistent match to the EPC database, including floor area, property type, age and general location. The database does not contain extensive data on attributes such as insulation, window type or lighting and no operational/occupier behavioural data. A matching process was undertaken to 'align' the databases, allowing models built in the sample data base to be deployed in the population database.

The sample data was subjected to a variety of standardised cleaning processes to remove anomalous data and missing observations – this data was removed from further analysis. The overall purging exercise resulted in a final useable data set of 106,895 observations for modelling (**Table 1**), representing approximately 15% of the Northern Ireland housing stock.

<<<Insert Table 1 Data by Property type and Age>>>

In this research, the role of sale price as the traditional dependant variable in hedonic pricing models is replaced by the creation of a discrete energy assessment metric, derived for each

[2] Full list available upon request

[3] Supplied by Land and Property Service (LPS) a governmental statutory body under the auspice of the Department of Personnel and Finance Northern Ireland

property. The energy assessment dependent variable is created by multiplying the score for CO_2 kg m^2 pa (kilograms of carbon dioxide per metre squared per annum) by the actual measured area in m^2 for each property, to culminate in a robust CO_2 Kg m^2 pa figure. This metric is obtained for all properties in both the 'current' condition (from the EPC assessment) and it's deemed "best cost effective improved" (potential) condition (this is a stated estimate on EPC certificates, along with the 'current' performance, allowing both 'current' and 'potential' to be modelled). This new set of metrics provides the dependant variables for the modelling and mass appraisal exercises which follow.

Computer Assisted Mass Appraisal (CAMA) exercise

To model the EPC derived energy assessment within the sample and deploy to the 'wider' population of property stock ('the unsold' – those devoid of an EPC assessment), a CAMA exercise is undertaken. This property taxation practice approach traditionally seeks to estimate a point value for all properties by analysing a subset of observations which have transacted – where the key attributes of the sold properties are utilised to predict the achieved sale price, within a traditional hedonic framework. A key facet of CAMA practice is that models must be constructed utilising attributes that are known in the wider population. As such, statistically significant explanatory variables only held for the modelling sample are of little use, unless the data can be captured for the population at large. This presents a challenge for the current research as there is limited information overlap between the attributes captured within the two respective datasets. This precludes deployment of the full EPC generating algorithm. Nonetheless, there was an *a priori* suspicion that a considerable amount of explanatory power of the EPC approach was derived from the key attributes present in both databases and capable of alignment. This interpretation was based on the reality of the inspection regime and the base knowledge of the building components with regards to their inherent energy performance. In essence, the capacity of a typical EPC assessor to discriminate between for example, different glazing systems, heating systems and embedded insulation within existing buildings which have not been subject to SAP rating or certificated previously is necessarily limited. The similarity in EPC score of basically similar properties lends credence to the idea that the base performance of the software is provided by basic building attributes, with considerable reliance on broad categorisation – such as 'double glazing' or 'gas fired central heating' rather than more detailed analysis. These features are also captured in a similar, somewhat broad way in a value assessment. This nevertheless required the exclusion of any non-shared attributes from the analysis and model development. Whilst this is an unfortunate restriction, it mirrors the reality of the traditional hedonic house price process – no pre-existing standard algorithm is available to fully explain the house price determination process – this is a somewhat 'black box' scenario which the hedonic methodology seeks to illuminate. This research treats the EPC derived scores as a similar 'black box' construct which are nevertheless the pertinent 'facts' in the market place. These are deemed to be the 'market' signals, with the modelling 'marked' to this market. As a consequence, the key attributes utilised were floor area, property type, era of construction and a proxy for location (no absolute location was used and no spatial econometrics were deployed). That said, traditional hedonic based CAMA derives much of its explanatory power from such limited inputs, despite value being influenced by a wide array of factors.

The parameter estimates are derived for key explanatory variables (**Table 2**) and a 'valuation model' is derived which best accounts for the variation in energy scores, and which ultimately will be applied to the wider population of properties. This stage encompassed various variable transformations into a binary state (dummy variables to incorporate categorical variables for model use) to create a list of suitable parameters to match the heterogeneous segmentation of the property types and market conditions. This was important in order to act as a proxy for factors such as construction methods which are omitted from the property characteristics due to lack of availability in the target population database. For example, older properties generally have higher ceilings and solid or early (shallow) cavity walls, whilst modern properties generally feature lower ceilings and insulated cavity walls. These characteristics are arguably captured through the interaction of variables, to capture the relationship between interior space and exterior surface and thus cubic volume which is likely to be an important factor in energy efficiency terms.

<<<Insert Table 2 Variable Descriptions>>>

The research examined the 'best fit' functional form of the hedonic framework in order to produce the most optimal and explanatory model for the mass appraisal exercise. This was necessary to better capture the non-linear nature of the relationships between factors such as price, energy efficiency and property characteristics. Numerous studies have been undertaken which demonstrate the potential of the technique in terms of both explanation and predictive capabilities for mass appraisal exercises in the property taxation field (Gloudemans and Miller, 1978; Mark and Goldberg, 1988). Whilst supporting the efficacy of the approach in general, standard economic theory does not suggest an appropriate functional form to be used in hedonic price equations (Rosen, 1974; Halvorsen and Pollakowski, 1979). Despite many such studies having been undertaken, there is limited theoretical guidance for the choice of functional model form, since it represents an equilibrium price schedule determined in the marketplace. In the absence of clear guidance, it is appropriate to test several functional forms. After testing a variety of hedonic specifications via an iterative process, it was determined that a multiplicative approach (log-log) was the most explanatory functional form preferable for modelling the energy performance and this was subsequently adopted within the research. The CAMA model form (involving 'unwinding' the log-log format is partiality detailed below[4] (Equation 1), with the overall model specification evidenced in Appendix 1.

$$\text{In\_currco2total\_est} = 144.504 + *\text{In\_TotalFloorArea}(\beta_1)\text{\^{}}.701 + 0.740\text{\^{}ptype\_apart}(\beta_2) + 1.375\text{\^{}ptype\_DETBung}(\beta_3) + \cdots 1.380\text{\^{}era\_04}(\beta_n)\ldots. \quad (1)$$

The CAMA modelling shows the 'in sample' analysis achieved an Adjusted R^2 of 0.679 to 'fit' the housing population attributes (**Table 3**).This process was subsequently replicated using the 'potential' energy assessment as the dependent variable. The results for the modelling of 'potential' using the log-log model form displayed a slightly improved performance with an Adjusted R^2 of 0.694, which is perhaps not surprising as this is an estimate of the performance of houses when all reasonable cost effective measures have been taken – lending itself even more towards a generalisation and categorisation rather than a more discrete score allocation.

<<< Insert Table 3 Hedonic functional specifications>>>

Modelling the tax effect

[4]For space reasons, this demonstrates the model multiplicative approach. The full model can be observed in Appendix 1.

Using the existing NI domestic property tax register and current tax rates (variously described as 'penny product', 'rate poundage' or 'millage rate' in practice), the research identified the base tax revenue currently charged under the NI domestic rating system and calculated the current tax bill for each property. The current tax revenue was then redistributed amongst the properties according to the two new tax bases created Current Energy Tax Base and Potential Energy Tax Base. The intention is to produce a revenue neutral position, with the Current and Potential Energy Tax bases raising the same amount of revenue as the current value tax base. In the case of the value based scenarios, this is according to each property's value as a proportion of the overall value. The Energy Tax scenarios follows this, with each property allocated an amount according to its CO_2 score, as a proportion of total CO_2, in each of the taxation jurisdictions (Local Government areas administrative units with different tax rates). The tax burden is distributed amongst the properties according to their individual proportion of the relevant total, generating a tax bill for each property for each of the modelled scenarios.

Standard property tax appraisal practice is to assess CAMA performance by directly comparing sale price (actual) with assessed value (predicted) (McCluskey et al. 2013). As the energy assessment does not have an assessed value as a target benchmark, this research utilises an approach advocated by Davis *et al*. (2012), who advocate comparing the tax bills which would have been generated under each approach. This subsequently allows for a direct like-for-like comparison to be carried out, utilising a number of specialist tests developed in the property tax literature and commonly deployed in the professional practice of mass appraisal for property tax purposes. This allows for the adoption of an energy tax approach to be quantified[5]. In effect, the modelling exercise devised a robust energy assessment algorithm. This was deployed in the wider population, estimating an energy score for every property. Tax base and tax rate analysis allowed the calculation of tax rates suitable to the new tax bases, on a revenue neutral basis. The new tax rates were applied to each property's energy scores to determine new tax bills which can be compared against the tax bills of the existing tax system. The analysis is measured employing standard tests for uniformity, fairness (a normative judgement) and equity used in property taxation ratio studies (IAAO 2013) , namely the Coefficient of Dispersion (CoD) and the Price-Related-Differential (PRD) as furnished in equations 2 and 3 respectively.

The COD statistic provides a measure of the variation of individual assessment ratios around the median. If the individual ratios are clustered closely around the median, the COD will be low, which implies the assessments are relatively uniform. However, if the individual ratios vary widely from the median, the COD will be high, which indicates that the property is not uniformly assessed. Statistically, the COD expresses the average absolute deviation of the individual ratios from the median ratio as a percentage of that median. The formula for COD is given as:

$$COD = \frac{100}{R_m}\left[\sum_{1}^{N}\frac{|R_i - R_m|}{N}\right] \tag{2}$$

[5]It must be noted that these 'tax bills' are raw estimates according to the sharing mechanism employed and do not encompass any reductions due to potential reliefs or exemptions which may, and often are, applied to property tax bills in the billing phase, which may be many and varied, with a variety of potential effects on the equity performance of the tax.

Where COD is the average percent of dispersion around the median assessment ratio; R_m is equal to the median assessment ratio; R_i is the observed assessment ratio for each parcel and N the number of properties sampled.

The Price-Related Differential is used as an indicator of assessment uniformity and to quantify the degree of "regressivity", where the lower-value properties are over-assessed relative to the higher-value properties, or "progressivity", where the lower-value properties are under-assessed relative to the higher-value properties. The benchmark range for PRD is between 0.98 and 1.03. If there is a tendency for the higher-valued properties to exhibit lower assessment ratios than lower-valued properties, the PRD will be greater than 1.03. If, on the other hand, higher-valued properties have higher assessment ratios than lower-valued properties, the PRD will be less than .98. In this regard, the price-related differential measures the pattern of inequity in assessments that has a correlation with the value of the property. Calculating the price-related differential assesses the mean assessment ratio - the sum of all ratios divided by the number of ratios. The formula for calculating the price-related differential is:

$$PRD = \frac{\sum_i \frac{\left[\frac{\hat{Y}_i}{Y_i}\right]}{n}}{\sum_i \left[Y_i * \left(\frac{\hat{Y}_i}{Y_i}\right)\right] / \sum_i Y_i} \tag{3}$$

4.0 Results and discussion

Overall Level Analysis

The initial analysis level looks at the model results at the District Council level (dissecting NI into the 26 local government areas in existence at the time of the research). At this level, the total energy score has been calculated and mapped (**Figure 1**). As illustrated, this indicates a significant "heat island" effect in the urban areas surrounding the major cities and conurbations. Indeed this finding was expected, given the *a priori* expectation that heavy concentrations of properties producing CO_2 manifestly reflect the density of development and associated density of energy consumption. Examination of the locations where most benefit can be derived from owners undertaking all cost-effective improvements, the picture remains relatively consistent. As evidenced in **Figure 1**, the areas with the highest propensity to reduce CO_2 are the core urban areas. It can be therefore identified that from one perspective, energy efficiency of housing is an urban problem – therefore policy focus should target urban areas. Following this rationale, most benefit can be gained by improving performance of property in urban areas - notably Belfast, where high spatial concentrations of energy consumption exists.

<<<Insert Figure 1 Energy Performance at the overall Level>>>

Median level Analysis

However, when further consideration is given to the actual nature of the challenge, it becomes clear that this is not an altogether 'true' depiction of the nature of the problem. Housing is, in reality, improved one at a time - albeit there may be opportunities for economies of scale in some instances, such as programmed upgrade of social housing schemes, or the laying of new gas infrastructure into areas of concentrated housing. Nevertheless, the 'truer' measure of the energy challenge is perhaps given by the *average* energy efficiency in an area, as observed in **Figure 2**. Examining the median (selected to reduce the effect of outliers and provide a more robust and consistent measure of central tendency), the analysis teases out a very different story, identifying urban properties to be "greener" than those located in more rural areas. This can perhaps be understood, given that urban properties are far more likely to have an increased level of attachment than rural properties and are on average, smaller. In addition, they are also far more likely to have their floor area arranged over two (or more) floors. This has the effect of having a higher ratio of cubic area to surface area – with the concomitant increased thermal efficiency – a lower ratio of interior to exterior. It would appear that within rural areas properties are suffering from what may be described as a "bungalowification" effect!

Taking this analysis angle further, examination of the median score for potential improvement of energy score, adopting all cost effective measures, can be observed in **Figure 2**. As evidenced, on a case by case basis, most benefit can be gained by improving performance of property residing in rural, as opposed to, urban areas. This twin level of analysis clearly identifies a difference between *areas* which consume a lot of energy (urban areas) and areas with *properties* that consume a lot of energy. This has considerable policy implications as it may well be the case that both measures and methods require to be tailored appropriately as a result. Indeed, where properties are inefficient, the appropriate message is likely to be to expend resources in appropriate physical improvements whereas areas where properties are more efficient may be more attuned to a behavioural message, relating to energy efficient occupational strategies.

<<< Insert Figure 2 Energy Performance at the Median Level>>>

Disaggregated Median level analysis

Whilst these insights are illuminating, the research further utilised more disaggregated census geography information to analyse the effects at a more granular level. The data was analysed at Electoral Ward level (508 smaller geographic units nesting within the 26 Local Government areas) with the median score results depicted in **Figure 3**. The findings undoubtedly present a more clouded picture of energy performance, illustrating that whilst it is apparent that urban areas still do better, there is far more of a 'patchwork quilt' effect. The graphical exposition identifies urban areas with good, average and poor energy performance. It also identifies more rural areas with good, average and poor energy performance. This disaggregated analysis therefore presents a more complex picture, in which it is harder to generalise. Despite this, it does offer an excellent improvement in terms of ability to identify poor performance which facilitates more accurate and targeted policy responses.

<<<Insert Figure 3 Energy Performance at the local Level>>>

The emerging findings suggest that the capture, intelligent merging and analysis of existing datasets, using well established techniques in novel ways can provide useful "high level" intelligence about the geographical dispersion of energy efficiency. As evidenced, the results highlight the potential to identify key locales where there is more of an energy efficiency problem, and significantly, locations where there is more to gain from corrective action. It is certainly the case that improving the quality of the data rigour within the modelling framework will augment the predictive accuracy and analytic power of the adopted approach. From a policy perspective, much can be gained from the sharing of datasets between taxation jurisdictions and energy performance assessment regimes, which in the UK context are not readily accessible. In this regard, there is also potential to generate 'Marriage Value' from sharing datasets between taxation and energy performance, given that the 2007 revaluation of residential property in NI excluded certain features (such as window type and heating type) which were deemed value significant in the sales sample but were not used in the modelling exercise or the mass appraisal for the tax base, as they were not robust in the unsold dataset. As evidenced within this research, this information has been captured for EPC purposes in approximately one fifth of the NI property portfolio and yet this data is not available for analysis which would have the potential to make the tax system fairer and more equitable. Additionally, considerable effort and expertise is put into collecting property attributes in jurisdictions around the world, with great potential to inform energy efficiency policy and practice, yet is not used for such purposes. Undeniably, this results in the underutilization of scarce resources and poses questions regarding the validity and utility of the property and energy performance data held.

The practical applications of this element of the research are clear and can be valuable in a variety of ways. Firstly, there are clear opportunities for the targeting of advertising for energy schemes in selecting the *mode or channel* such as targeted mail shots in rural areas where there are relatively fewer properties, but more to gain (justifying the cost of postage). As mentioned earlier, there is perhaps also the potential for tailoring *messages* to appropriate user groups: a user behaviour focused message where performance of stock *generally* good with an asset improvement message where performance of stock is *generally* weak. It also offers an improved knowledge of the housing stock, to facilitate potentially powerful policy options such as 'greening' of the property tax as part of the so called "Green Deal". Appositely, this taxation mechanism has definite capacity in providing a method to leverage the somewhat limited value effect of energy efficiency performance.

A Green Tax?

To investigate this further, the research undertook a 'revenue neutral' tax reallocation, to measure the incidence of tax reassignment from a value basis to an energy efficiency basis. The results emerging from this novel approach are illuminating. It is evident that, on an overall basis, the performance would be largely similar – a consequence of the similar attributes informing both bases. The ratio analysis, in line with international mass appraisal best practice, but applied at the tax bill level are depicted in **Table 4**. The PRD lies well within the target range, suggesting that the redistribution is benign across the entirety of the value range. This is interesting, as it would be difficult to deploy policies which perform *regressively*, and thereby loading additional cost on lower value properties. It is also practically difficult to deploy policies which are blatantly *progressive*, loading tax burden on higher value properties, often owned by those who are adept at challenging such approaches. Analysis of the COD tells a somewhat different story. The COD falls *well outside* the acceptable range, indicating that the new tax base has redistributed the tax burden amongst properties, with some paying more and some paying less. This demonstrates that the policy option is having an effect, with definite annual financial consequences for homeowners – the kind of driver which has the potential to focus minds and drive behaviour.

<<<Insert Table 4 Ratio statistics based on the PRD and COD>>>

The overall picture of tax incidence change is not necessarily 'even' at a sub market level. To investigate this, the PRD and COD were calculated at Local Government level (**Figure 4**). The findings reveal considerable differences in the effect, with some geographical areas performing markedly different from the 'current' system. It is notable that the highest COD's are experienced in the more rural areas, towards the East and South East of NI, whereas the heavily urban areas in the East of NI exhibit the least redistribution.

<<<Insert Figure 4 spatial distribution of Ratio statistics>>>

How this redistribution is manifesting itself is considered further (**Figure 5)**. The analysis indicates that fully rural properties would incur a significantly increased tax burden under an energy based tax system, whereas fully urban property appears to be similar under both taxation approaches. The counterbalancing effect is that suburban properties would pay significantly less and would have the most to gain from undertaking any identified upgrades. Rural properties appear to have relatively little to gain from undertaking identified upgrades[6]. Whilst this does raise problems of fairness and equity with regards to rural taxpayers, NI has traditionally had the most liberal regulations with regards to rural housing provision, resulting in a much less dense development form, aided by a strong rural lobby. This places a variety of stresses on the finances of public service delivery and inevitably generates additional CO_2 from transport sources. Through this 'lens' the additional tax burden may seem somewhat 'fairer'.

<<<Insert Figure 5 Overall Effect by Setting>>>

With regards to the 'overall' effect by property type (**Figure 6**), the results suggest that apartments have the most to gain when changing the tax base, paying considerably less under an energy based system. Mirroring the setting analysis, semi-detached houses, typical in suburban locations, would benefit significantly, perhaps understandable as the majority of semi-detached properties in NI have cavity walls and are capable of retrofit to high thermal standards. Perhaps the biggest surprise of the research findings is the performance of detached bungalows – identified earlier as the likely most energy inefficient on the basis of basic design concept. The analysis suggests that such properties would benefit significantly by a change to an energy taxation basis. This is likely to arise due to the relative price premium paid for such properties in the market – that is, the energy use issue which might tend to *increase* the liability is insufficient to offset the relative *over* taxation due to market desirability.

<<<Insert Figure 6 Overall Effect by type>>>

The effects of redistribution by the age of property are demonstrated in **Figure 7**. The delineation is quite stark, with the oldest properties (1 & 2) paying a significantly higher

[6]Of course, such analysis is predicated on all properties undertaking all upgrades, with the full tax burden redistributed accordingly.

amount under an energy based system, with the newest properties (5) paying considerably less. Whilst this is an *a priori* expectation, it is important to have such theories tested. The result of wholesale upgrade provides a slightly more unusual picture, with both oldest properties and newest properties paying more as a result of improving – however the newest properties still pay considerably less than under a value based system.

<<<Insert Figure 7 Overall Effect by Age>>>

5.0 Conclusions

The growing concern pertaining to energy performance within residential housing stock has seen an increasing policy focus on improving the sectors environmental performance. The introduction of mandatory energy efficiency certification in the EU was envisaged to be a key policy driver: in terms of providing reliable information on the energy performance of dwellings to buyers; in helping to change consumer behaviour towards how they perceived the economics of energy efficient housing and in fostering an increased willingness to pay for it. Despite these policy initiatives, understanding energy performance within the residential housing stock remains challenging. Research results have been mixed, with some studies showing a positive association between property price and EPCs – whilst other studies showing no 'real' relationship. Further studies show low confidence in the metrics from professionals and poor consumer recognition. This all adds to the complexity associated with evidence based policy decision making.

Regardless of the extent to which EPCs are capitalized into property, a central concern remains surrounding the lead in time for a more extensive residential coverage of energy assessment - which is likely to be considerable. To proactively address energy performance, policy makers need an enhanced understanding of the performance of the entire housing stock. In contrast to much of the existing literature examining EPCs, this research has attempted to move the analysis further, by examining energy performance 'beyond' the sample of EPC possessing properties, towards the wider housing stock. In this regard, the research findings and significance of the study have clearly identified, through a mass appraisal exercise, how tax incentivisation can be applied, and furthermore provided a useful assessment paradigm and effective methodology which can readily be applied in other jurisdictions. The research demonstrates the value of combining large datasets of often publicly collated data, for multiple policy objectives – in this instance better understanding property attributes for tax equity purposes and to address energy efficiency challenges.

The findings of this research clearly contribute to the policy debate surrounding the implementation of energy efficiency certification, through a greater understanding of the geographical dispersion of energy efficiency. It provides high level research to help guide policy and decision-making by facilitating the creation of a 'road map' which identifies key locales where there is more of a *problem* and locales where there is more to *gain,* helping in terms of targeting energy improvement. The results indicate that whilst assessing the energy performance of houses can be a complex process involving many parameters, much of the explanatory power can be achieved *via* a relatively small number of input variables, often already held by property tax authorities. This offers the opportunity for useful housing stock modelling – such as the savings possible from power switching. The research also identifies that whilst urban areas display the expected 'heat island' effect in terms of energy consumption, urban properties are on average *more efficient* than suburban and rural properties. This provides evidence for tailoring energy efficiency messages – between stock improvement where efficiency is lower and behaviour modification where the stock is more efficient. Finally, the research investigates the potential effects of 'greening' the property tax and demonstrates that outcomes may be more complex than *a priori* expectations. This provides a valuable 'test bed' for undertaking pre implementation impact assessment of a variety of tax base switching and hybridisation options (such as a property tax partially based on value and partially on energy score).

As with other similar studies, data deficiencies introduce an element of omitted variable bias as the 'basket' of available property attributes for modelling is necessarily limited to those well populated in the wider population of properties in which the appraisal model will be deployed. This limits the overall performance of the mass appraisal exercise. That said, the research demonstrates the benefits of sharing data and improving knowledge of the housing stock in its totality. Future research incorporating specific energy efficient features would greatly aid conceptual understanding of how, or if, particular attributes are capitalized into property value. The findings emanating from this research illustrate that energy efficiency remains complex and difficult to accurately quantify, given the idiosyncratic nature of property as an asset class. Nevertheless, without improving both market knowledge of the energy efficiency of housing, and without research of this nature which seeks to evidence energy assessment for properties remaining 'outside' the parameters of EPC assessment, it is challenging to establish how behavioural change can be fostered. As this research has demonstrated, changing the tax code towards an energy 'tax bill' has clear advantages for particular house types of particular ages, sizes and in different locations which is arguably intrinsically captured by the EPC assessments - illustrating that a more viable conduit through taxation may be a positive driver, although in no way a panacea.

References

Australian Bureau of Statistics 2008 Energy Efficiency Rating and House Prices in the ACT, Report for Department of the Environment, Water, Heritage and Arts

Banfi, S., Farsi, M., Filippini, M. and Jakob, M. (2008), "Willingness to pay for energy-saving measures in residential buildings", Energy Economics, Vol. 30 No. 2, pp. 503-516.

Banks, N., 2008, Implementation of Energy Performance Certificates in the Domestic Sector, UK Energy Research Centre 2008/001, Working Paper, UKERC, Oxford.

Berry, S., Marker, T. and Chevalier, T. (2008), "Modeling the relationship between energy efficiency attributes and house price: the case of detached houses sold in the Australian capital territory in 2005 and 2006", 2008 ACEEE Summer Study on Energy Efficiency in Buildings, pp. 2.52-2.56, available at: www.aceee.org/sites/default/files/publications/proceedings/SS08_Panel2_Paper05.pdf.

Brounen, D. and Kok, N. 2011 On the Economics of Energy Labelling in the Housing Market, Journal of Environmental Economics and Management, 62, 166- 179

Boverket (2009a), Regelsamling fo¨ r byggande, BBR 2008. Supplement Februari 2009, 9 Energihusha° llning, BFS 1993:57 med a¨ ndringar t.o.m. BFS 2008:20 (Building Regulation Code, Energy), Boverket, Karlskrona (in Swedish).

Boverket (2009b), "Utva¨rdering av systemet med energideklarationer" (Evaluation of the energy performance certificate system") (Uppdrag nr 12 Uppfo¨ljning av energideklarationer enligt regleringsbrev fo¨r budgeta°ret 2009 avseende Boverket. M2008/4791/A) (in Swedish).

Cerin, P., Hassel, L. G., & Semenova, N. (2014). Energy Performance and Housing Prices. *Sustainable Development*, *22*(6), 404-419.

Davis, P. T., McCord, J., McCord, M. J., & Haran, M. (2015). Modelling the effect of energy performance certificate rating on property value in the Belfast housing market. *International Journal of Housing Markets and Analysis*, *8*(3), 292-317.

Dubin, J. (1992), "Market barriers to conservation: are implicit discount rates too high?", 1992 Proceedings of the POWER Conference on Energy Conservation, University of California Energy Institute, Berkeley, CA, June, pp. 21-33.

Entrop, A.G., Brouwers, H.J.H. and Reinders, A.H.M.E. (2010), "Evaluation of energy performance indicators and financial aspects of energy saving techniques in residential real estate", Energy and Buildings, Vol. 42 No. 5, pp. 618-629.

EU Directive 2002/91/EC (2010), Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the Energy Performance of Buildings, available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri¼OJ:L:2003:001:0065:0065:EN:PDF

Eves, C., & Kippes, S. (2010). Public awareness of "green" and "energy efficient" residential property: An empirical survey based on data from New Zealand. *Property Management*, *28*(3), 193-208.

Deng, Y. Li, Z. and Quigley, J. 2011 Economic Returns to Energy-Efficient Investments in the Housing Market: Evidence from Singapore, Regional Science and Urban Economics, 42, 685-694

Dinan, T. and Miranowski, J. 1989 Estimating the implicit price of energy efficiency improvements in the residential housing market: A hedonic approach. Journal of Urban Economics, 25(1), 52-67.

Fawcett, T., & Boardman, B. (2009). Housing market transformation. *Proceedings of European Council for an Energy Efficient Economy. Summer Study*.

Fregonara, E., Rolando, D., Semeraro, P., & Vella, M. (2014). The impact of Energy Performance Certificate level on house listing prices. First evidence from Italian real estate. *Aestimum*, (65), 143-163.

Fuerst, F., McAllister, P., van de Wetering, J., & Wyatt, P. (2011). Measuring the financial performance of green buildings in the UK commercial property market: addressing the data issues. *Journal of Financial Management of Property and Construction*, *16*(2), 163-185.

Fuerst, F., Nanda, A., & Wyatt, P. (2013). *Energy Labelling and Residential House Prices: Some Evidence from the United Kingdom* (No. eres2013_246). European Real Estate Society (ERES).

Fuerst, F. and McAllister, P. 2011a Green Noise or Green Value: Measuring the Price Effects of Environmental Certification in Commercial Buildings, Real Estate Economics, 39 46-69.

Fuerst, F., McAllister, P., van de Wetering, J. and Wyatt, P 2010. Establishing a Data Framework for Measuring the Price Effects of Eco-certification. RICS Fibre Research Report: Findings in Built Environments.

Fuerst, F., McAllister, P., Nanda, A., & Wyatt, P. (2015). Does energy efficiency matter to home-buyers? An investigation of EPC ratings and transaction prices in England. *Energy Economics*, *48*, 145-156.

Fuerst, F., McAllister, P. M., Nanda, A., & Wyatt, P. (2013). Is Energy Efficiency Priced in the Housing Market? Some Evidence from the United Kingdom. *Some Evidence from the United Kingdom (February 26, 2013)*.

Högberg, L. (2013). The impact of energy performance on single-family home selling prices in Sweden. *Journal of European Real Estate Research*, *6*(3), 242-261.

Hodge, T. R., McMillen, D. P., Sands, G., & Skidmore, M. (2016). Assessment inequity in a declining housing market: The case of Detroit. *Real Estate Economics*.

Hyland, M., Lyons, R. and Lyons, S. (2013), The value of domestic building energy efficiency: evidence from Ireland, Energy Econ., 40 (2013), pp. 943–952

IAAO, (2013). Standard on Ration Studies. Kansas: International Association of Assessing Officers.

Kok, N. and Kahn, M.E. (2012), "The value of green labels in the Californian housing market: an economic analysis of the impact of green labeling on the sales price of a home", Working Paper 2012-07-19, available at: www.corporate-engagement.com/research

Laquatra, J., Dacquisto, D.J., Emrath, P. and Laitner, J.A. (2002), "Housing market capitalization of energy efficiency revisited", 2002 ACEEE Summer Study on Energy Efficiency in Buildings, pp. 8.141-8.151, available at: www.reneuer.com/category/?category_id¼13&document_id¼125

McNamara, P. (2008) *Will Greener Buildings Bring Bigger Profits?* Professional Investor*,* pp. 41:43. Available at: www.cfauk.org

McCluskey, W. J., Davis, P., McCord, M., McIlhatton, D., & Haran, M. (2013). Computer assisted mass appraisal and the property tax. A Primer on Property Tax: Administration and Policy, 307-338.

Nair, G., Gustavsson, L. and Mahapatra, K. (2010), "Owners perception on the adoption of building envelope energy efficiency measures in Swedish detached houses", Applied Energy, Vol. 87 No. 7, pp. 2411-2419.

Nair, G., Gustavsson, L., & Mahapatra, K. (2010). Factors influencing energy efficiency investments in existing Swedish residential buildings. *Energy Policy*, *38*(6), 2956-2963.

Nevin, R. and Watson, G. (1998), "Evidence of rational market valuations for home energy efficiency", The Appraisal Journal, Fall, pp. 401-409.

Nevin, R.,Bender, C. andGazan,H. (1999), "Construction and the appraiser:more evidence of rational market values for home energy efficiency", The Appraisal Journal, Fall, pp. 454-460.

OECD/IEA (2008), Energy Policies of IEA Countries – Sweden 2008 Review, OECD/IEA, Paris, available at: www.iea.org/textbase/nppdf/free/2008/sweden2008.pdf

Popescu, D., Boazu, R., Bienert, S. and Schu¨tzenhofer, C. (2009a), "Analysis of the influence of energy performance of buildings on the romanian real-estate market", IMMOVALUE Project Report, available at: www.immovalue.org/papers.htmL

Popescu, D., Mladin, E.C., Boazu, R. and Bienert, S. (2009b), "Methodology for real estate appraisal of green value", Environmental Engineering and Management Journal, Vol. 8 No. 3, pp. 601-606.

Sayce, S., Sundberg, A., & Clements, B. (2010). Is sustainability reflected in commercial property prices: an analysis of the evidence base, **Rics** Research, (January, 2010); London
Available at: http://eprints.kingston.ac.uk/15747/1/Sayce-S-15747.pdf

Tversky, A., & Kahneman, D. (1991). Loss aversion in riskless choice: A reference-dependent model. The quarterly journal of economics, 1039-1061.

Watts, C., Jentsch, M. F., & James, P. A. (2011). Evaluation of domestic Energy Performance Certificates in use. *Building Services Engineering Research and Technology*, *32*(4), 361-376.

Waters, M., & Elder, B. (2007). *Green Values and the UK Residential Market: The Impact of Energy Performance Certificates on Property Value* (No. eres2007_316). European Real Estate Society (ERES).

APPENDIX 1

	B	t	sig	Expo(B)	x^n	Eg. Total Area $^{.701}$
(Constant)	4.973	300.787	0.000	144.504	*	
Ln area	.701	205.968	0.000	Total Area	^	.701
DET Bung	.319	90.435	0.000	1.375	^	DET Bung
DET House	.259	75.148	0.000	1.296	^	DET House
SDT Bung	.206	46.419	0.000	1.229	^	SDT Bung
SDT House	.151	58.170	0.000	1.163	^	SDT House
TER Bung	.034	6.103	.000	1.035	^	TER Bung
APT	-.301	-90.672	0.000	0.740	^	APT
BT01	-.199	-8.181	.000	0.819	^	BT01
BT02	-.188	-6.522	.000	0.829	^	BT02
BT03	-.303	-6.217	.000	0.738	^	BT03
BT04	-.026	-3.094	.002	0.974	^	BT04
BT05	-.053	-6.942	.000	0.948	^	BT05
BT06	-.011	-1.262	.207	0.989	^	BT06
BT07	-.093	-10.619	.000	0.911	^	BT07
BT08	.021	2.274	.023	1.021	^	BT08
BT09	-.002	-.286	.775	0.998	^	BT09
BT10	.056	4.169	.000	1.057	^	BT10
BT11	.003	.311	.756	1.003	^	BT11
BT12	-.123	-13.610	.000	0.885	^	BT12
BT13	-.106	-12.420	.000	0.899	^	BT13
BT14	-.131	-15.299	.000	0.878	^	BT14
BT15	-.089	-10.667	.000	0.915	^	BT15
BT16	-.005	-.403	.687	0.995	^	BT16
BT17	-.077	-8.827	.000	0.925	^	BT17
BT18	-.052	-4.700	.000	0.949	^	BT18
BT19	.027	3.268	.001	1.027	^	BT19
BT20	.011	1.261	.207	1.011	^	BT20
BT21	.025	1.705	.088	1.025	^	BT21
BT22	.041	4.045	.000	1.042	^	BT22
BT24	.093	8.052	.000	1.097	^	BT24
BT25	.089	7.201	.000	1.093	^	BT25
BT26	.103	6.448	.000	1.108	^	BT26
BT27	.035	3.455	.001	1.036	^	BT27
BT28	.000	.056	.956	1.000	^	BT28
BT29	.144	9.872	.000	1.154	^	BT29
BT30	.072	7.786	.000	1.075	^	BT30
BT31	.008	.459	.646	1.009	^	BT31
BT32	.047	4.538	.000	1.048	^	BT32
BT33	.069	5.189	.000	1.071	^	BT33
BT34	.035	4.155	.000	1.036	^	BT34
BT35	.023	2.564	.010	1.024	^	BT35

BT36	-.046	-5.760	.000	0.955	^	BT36
BT37	-.021	-2.277	.023	0.980	^	BT37
BT38	.003	.318	.750	1.003	^	BT38
BT39	.099	9.565	.000	1.104	^	BT39
BT40	.036	3.933	.000	1.037	^	BT40
BT41	.050	5.836	.000	1.051	^	BT41
BT42	.101	11.004	.000	1.106	^	BT42
BT43	.089	8.268	.000	1.094	^	BT43
BT44	.069	5.841	.000	1.071	^	BT44
BT45	.127	13.414	.000	1.136	^	BT45
BT46	.075	4.746	.000	1.078	^	BT46
BT47	.078	10.208	.000	1.082	^	BT47
BT48	.071	9.127	.000	1.074	^	BT48
BT49	.063	7.149	.000	1.065	^	BT49
BT51	.136	13.598	.000	1.145	^	BT51
BT52	.093	9.629	.000	1.098	^	BT52
BT53	.052	5.483	.000	1.054	^	BT53
BT54	.148	10.132	.000	1.159	^	BT54
BT55	.160	13.247	.000	1.173	^	BT55
BT56	.147	12.185	.000	1.159	^	BT56
BT57	.064	3.592	.000	1.066	^	BT57
BT60	.048	4.846	.000	1.049	^	BT60
BT61	.086	6.757	.000	1.089	^	BT61
BT62	.092	10.821	.000	1.096	^	BT62
BT63	.100	9.370	.000	1.106	^	BT63
BT64	.093	3.611	.000	1.097	^	BT64
BT65	.065	4.622	.000	1.067	^	BT65
BT66	.107	12.055	.000	1.113	^	BT66
BT67	.094	8.839	.000	1.098	^	BT67
BT68	.038	.989	.323	1.039	^	BT68
BT69	-.014	-.453	.650	0.986	^	BT69
BT70	.058	4.598	.000	1.060	^	BT70
BT71	.052	5.850	.000	1.054	^	BT71
BT74	.075	7.032	.000	1.078	^	BT74
BT75	.083	3.483	.000	1.086	^	BT75
BT76	.064	1.878	.060	1.066	^	BT76
BT77	.078	1.565	.118	1.081	^	BT77
BT78	.059	6.130	.000	1.061	^	BT78
BT79	.022	2.191	.028	1.022	^	BT79
BT80	.060	6.175	.000	1.062	^	BT80
BT81	.051	2.874	.004	1.053	^	BT81
BT82	.056	5.601	.000	1.058	^	BT82
BT92	.023	1.889	.059	1.023	^	BT92
BT93	.010	.665	.506	1.010	^	BT93
BT94	.053	4.210	.000	1.055	^	BT94
era_01	.694	179.028	0.000	2.002	^	era_01

era_02	.608	164.555	0.000	1.838	^	era_02
era_03	.415	153.470	0.000	1.515	^	era_03
era_04	.322	114.417	0.000	1.380	^	era_04

Tables

<Table 1> Data by Property type and Age

	Original Data		Cleansed Data	
Type	N	Percent	N	Percent
	185	0.1		
Apartment	24661	17.1	16436	15.4
DET Bung	15883	11	12702	11.9
DET House	18361	12.7	11872	11.1
SDT Bung	7098	4.9	6024	5.6
SDT House	30427	21	21677	20.3
TER Bung	3957	2.7	3725	3.5
TER House	44041	30.5	34459	32.2
Total	144613	100	106895	100
Age				
	36133	25		
<1919	9670	6.7	9559	8.9
1919-1949	11539	8	11467	10.7
1950-1973	32335	22.4	31833	29.8
1974-1991	24246	16.8	23984	22.4
1992>	30690	21.2	30052	28.1
Total	144613	100	106895	100

<Table 2> Variable Descriptions

Variable	**Description**	**Type**
CO_2 Kg m^2 pa + (*ln*)	Discrete energy assessment of level carbon dioxide per kilogram per metre squared per annum and it's logarithmic state	C
House Type	Type of property (Transformed to binary e.g. 1 if TER; 0 otherwise)	B
Age	Age of the property (Transformed to binary e.g. 1 if <1919 ; 0 otherwise)	B
Floor Area + (*ln*)	Total floor area (m^2) and logarithmic total floor area (m^2)	C
Location	Location of property (Transformed to binary e.g. 1 if WARD; 0 otherwise)	B

C: Continuous; B: Binary

<Table 3> Hedonic functional specifications

	Standard	**semi-log**	**Log-Log**
Adj. R2	0.619	0.661	0.679

F-statistic	1981.385*	2315.923*	2516.064*

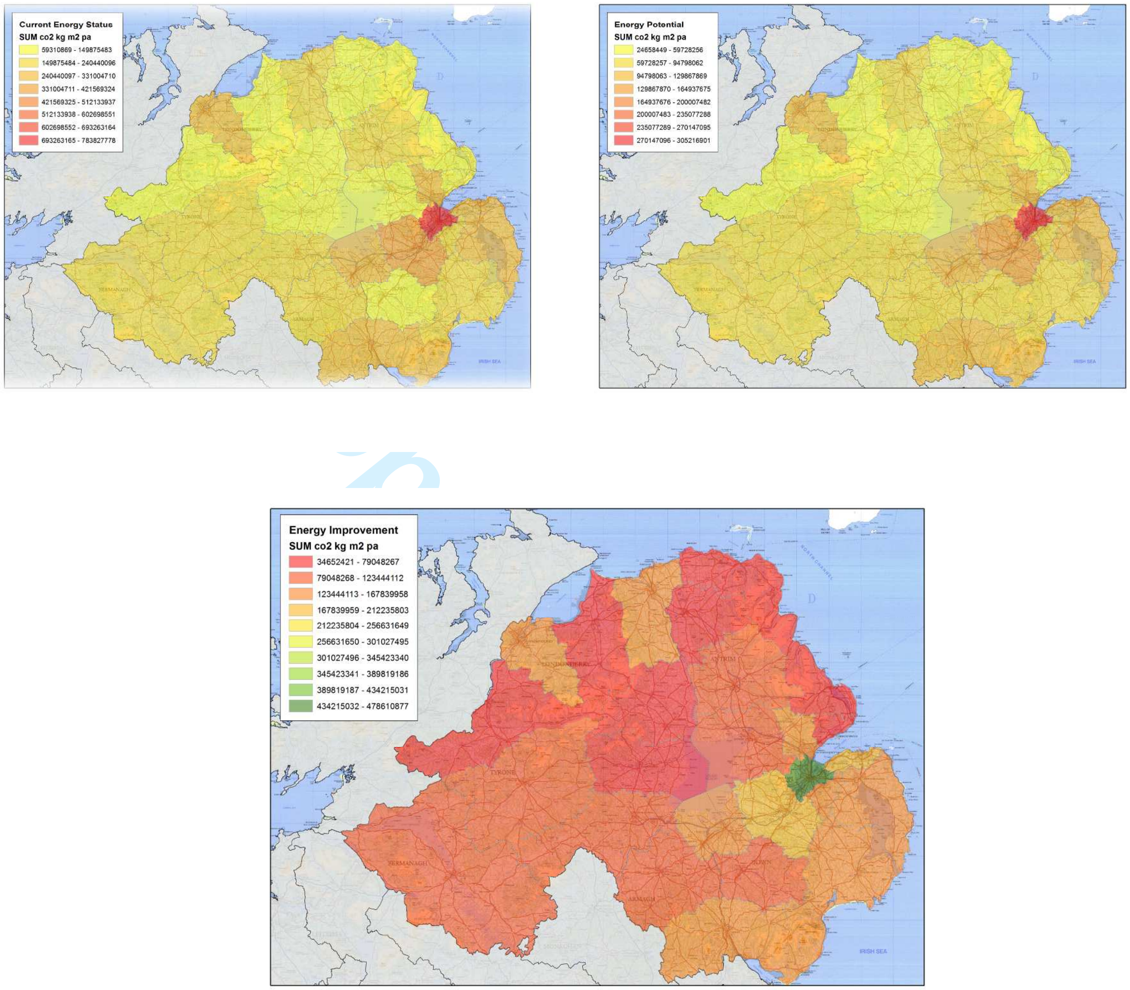
**denotes significant at the 99% level*

<Table 4> Ratio statistics based on the PRD and COD

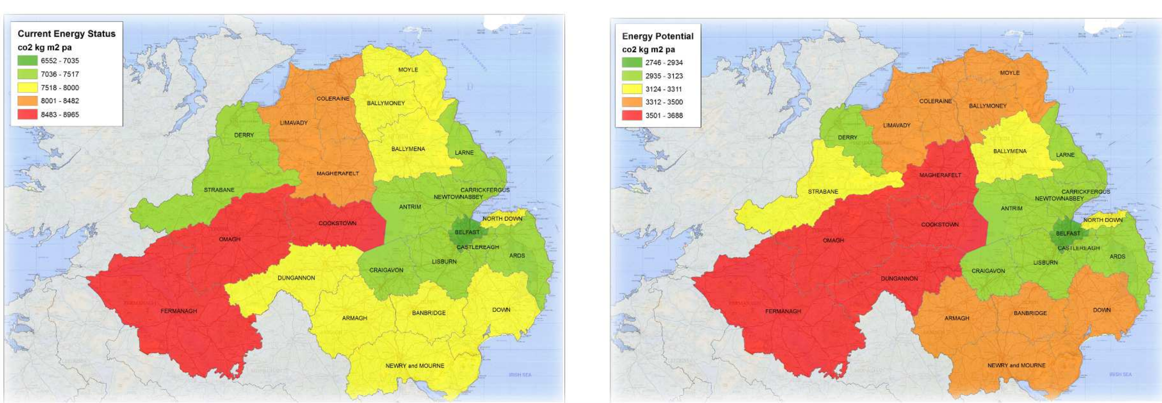
Ratio	Statistic
PRD Current	1.003
PRD Improved	1.0043
COD Current	0.249
COD Improved	0.251

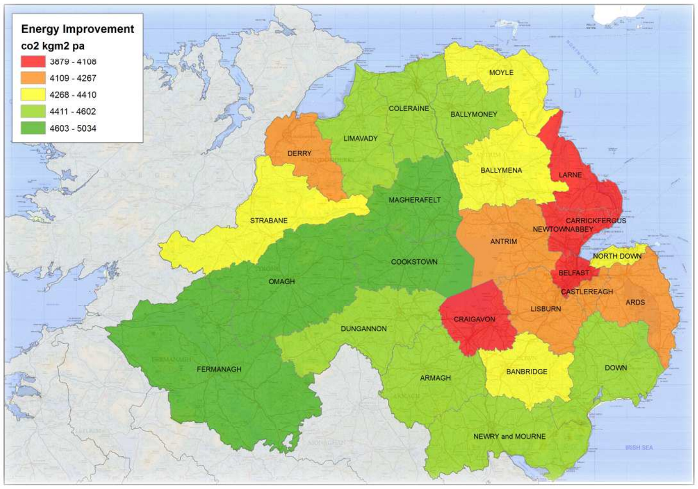
Figures

<Figure 1> Energy Performance at the overall Level

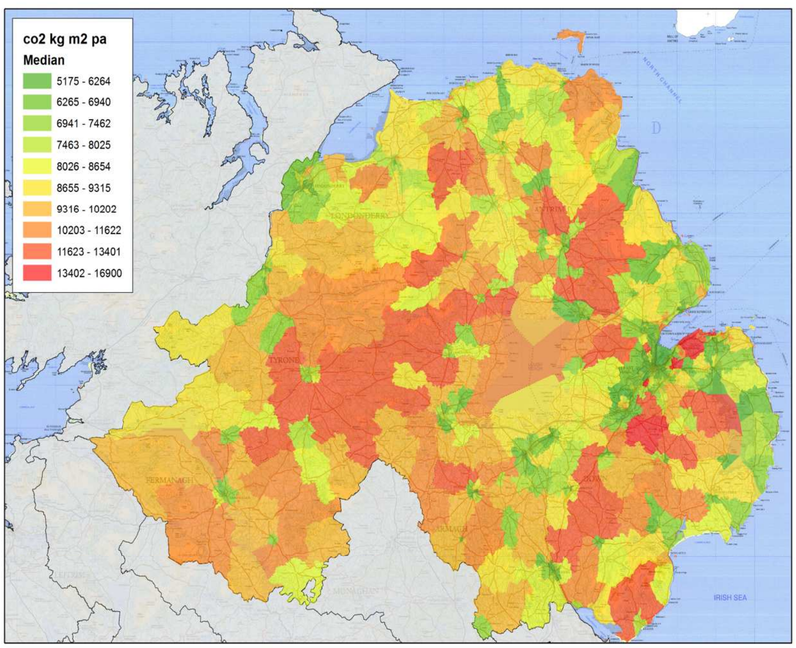


<Figure 2> Energy Performance at the Median Level

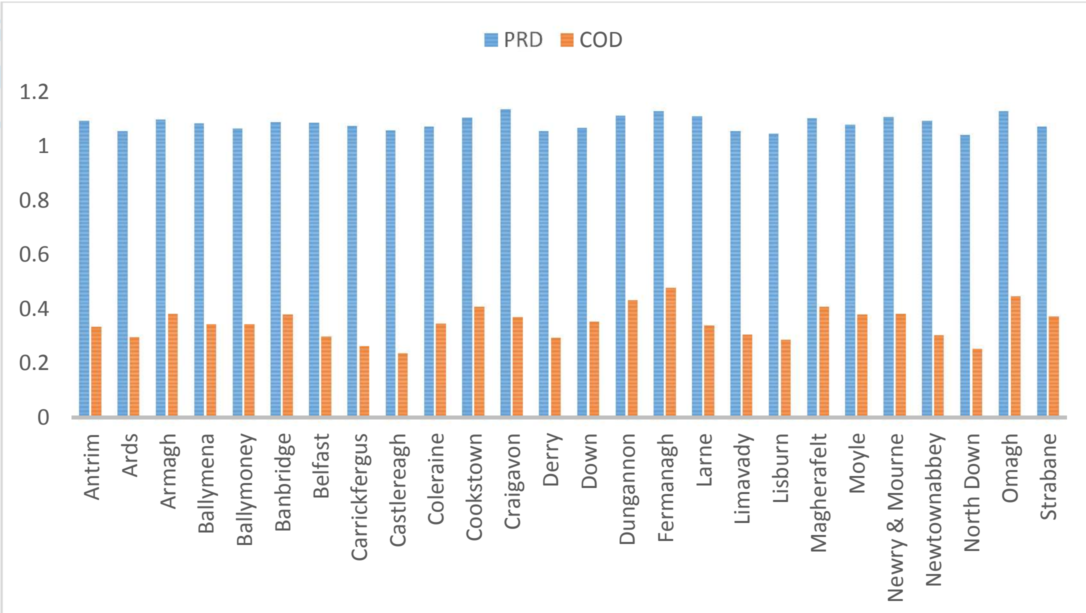




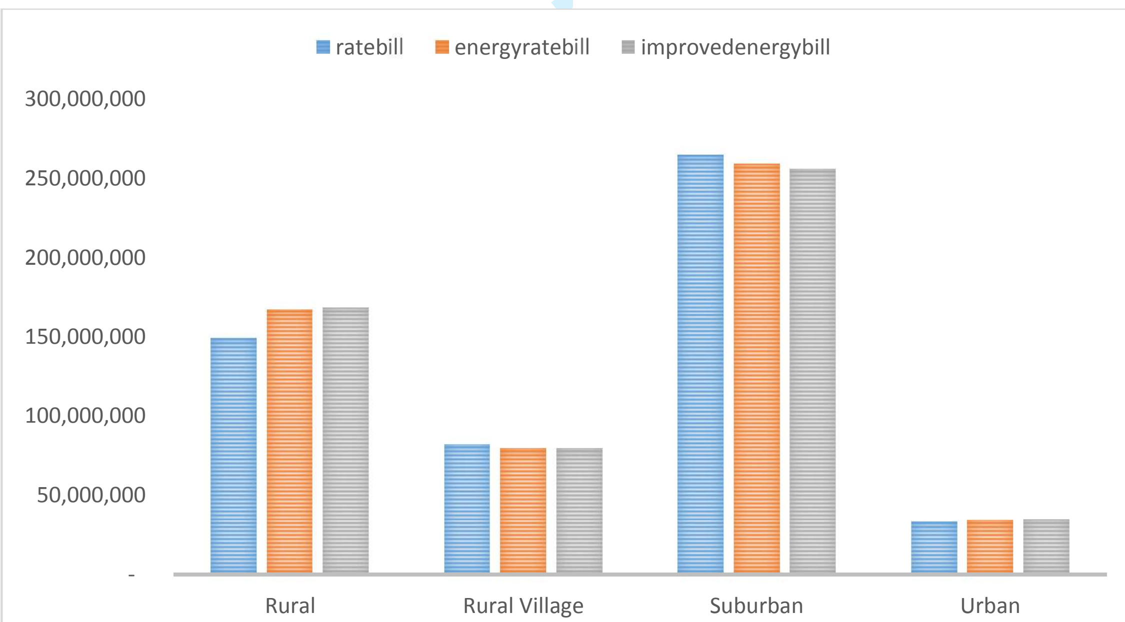
<Figure 3> Energy Performance at the local Level



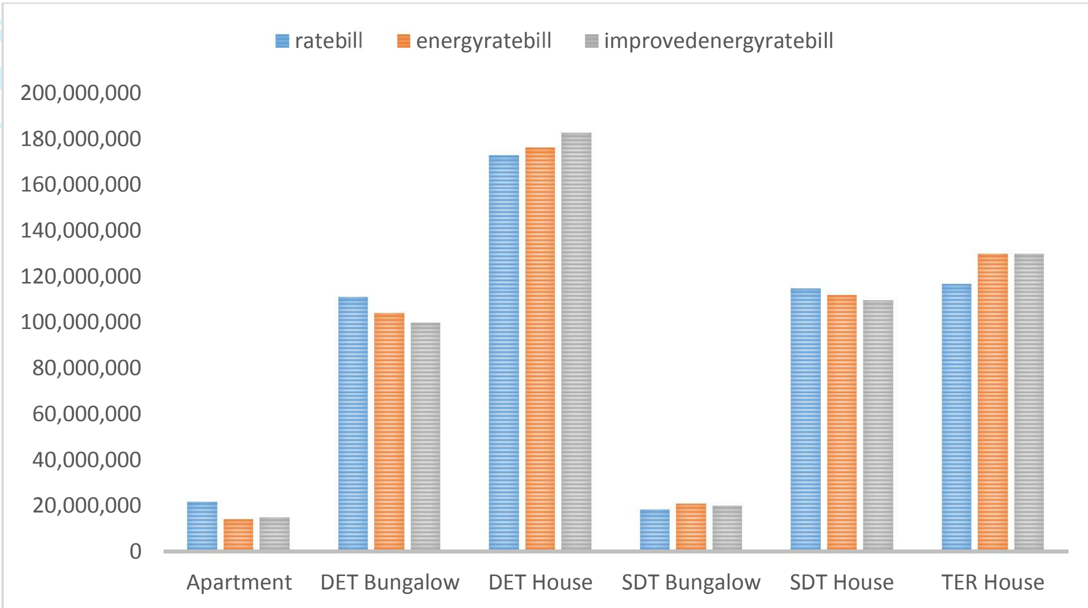
<Figure 4> spatial distribution of Ratio statistics



<Figure 5> Overall Effect by Setting



<Figure 6> Overall Effect by type



<Figure 7> Overall Effect by Age